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Investigating greenhouse challenge from growing trends of electricity consumption through home appliances in buildings

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ABSTRACT

Energy use in buildings accounts for 38% of global total final energy consumption, 45% of which in OECD countries. According to the International Energy Agency the continuing demand for new large and small appliances, often with new functionality, is resulting in rapidly increasing electricity consumption in both the residential and service sectors. Appliances contribution to the residential electricity use is increasing. Also, appliances types are changing in our homes. This paper aims to find the trend of energy consumption of appliances in the building sector and describing the driver of this energy consumption. For doing so, a review of the literature available in the topic is summarized first. Trends show that appliances energy consumption is growing, but also that are disproportionately powered by electricity, mainly due to the proliferation of electronics and other small household devices, especially in OECD countries. This trend, which have already brought millions of households out of poverty in China and India and promises to continually improve standards of living throughout the developing world, will also have a major impact on appliance energy consumption as many more households will be able to afford basic equipment such as refrigerators and washing machines. Moreover, because appliances generally consume electricity instead of renewable fuels or direct combustion fuels, they carry a relatively large carbon footprint in countries where electricity production is carbon intensive. Finally, appliances present significant opportunities for efficiency improvement, since most of the appliances to be implemented in the near future still have to be produced.

Contents

1. Introduction

According to the International Energy Agency [1,2] energy use in buildings accounts for 38% of global total final energy consumption. Of this, 45% is consumed in OECD countries and around 55% in non-OECD countries.

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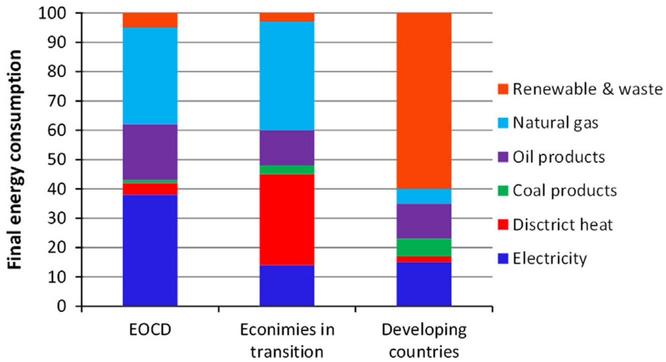


Fig. 1. Final energy consumption in buildings by region, 2005.
Source: adapted from [1].

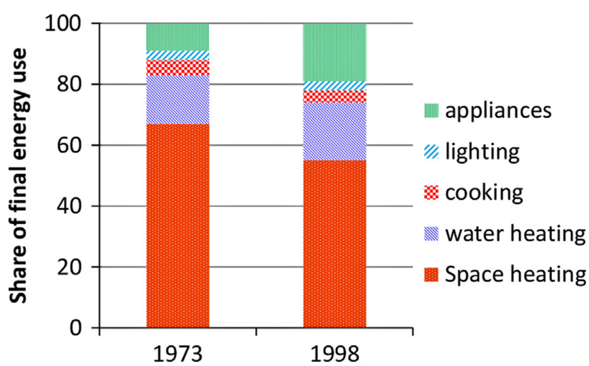


Fig. 2. Share of final energy use in buildings.
Source: adapted from [6].

Fig. 1 shows that different world regions have different energy use patterns. In OECD countries, natural gas and oil products dominate energy consumption, primarily due to the importance of space heating. In transition economies, district heating plays and important role that, together with gas, accounts for heating and cooking accounts for 56% of total energy consumption. Electricity accounts for 15% and reflects low electrification rates in many developing countries. Economic development in non-OECD countries therefore portends a greater overall share of electricity in buildings worldwide, and a significant increase in non-renewable fuel usage.

According to the International Energy Agency [3] the continuing demand for new large and small appliances, often with new functionality, is resulting in rapidly increasing electricity consumption in both the residential and service sectors. Given the high CO_2 intensity of electricity generation in many developing countries, and their rapid economic growth, energy efficiency for lighting and appliances will be an important abatement area, as confirmed in recent studies [4,5]. Fig. 2 shows that from the final energy use of buildings, appliances grow from 9% in 1973 to 19% in 1998, including space cooling.

In 1973, appliances (including space cooling) accounted for roughly half of the residential electricity use in the group of eleven IEA countries (IEA-11). By 1998, this share had increased to 58%. On the other hand, and as comparison, the share of electricity for space heating grew only from 13 to 16% [6]. Roughly two-thirds of the doubling of IEA-11 electricity demand between 1973 and 1998 came from appliances. Traditional “big appliances” such as clothes washers and refrigerators dominated the growth in appliance electricity consumption through the early 1980s, while much of the recent growth is due to the use of “miscellaneous” appliances, such as home electronics and small kitchen gadgets.

Fouquet et al. [7] accounted the energy consumption taking into consideration the changes between energy consumption in 1800 and 2000. They state that, “The economic history of light shows how focussing on developments in energy service provision rather than simply on energy use and prices can reveal the ‘true’ declines in costs, enhanced levels of consumption and welfare gains that have been achieved”

Firth et al. [8] presented a monitoring study of the electrical consumption in UK by a residential building due to appliances. They concluded that there is great variation in the annual electricity consumption of the dwellings, the annual electricity consumption of the dwellings increased from the first to the second year of monitoring the domestic buildings, and the users were responsible for the overall increase in electricity consumption in the monitored dwellings. These authors stated that the overall increase in electricity consumption is attributed to a 10.2% increase in the consumption of ‘standby’ appliances (such as televisions and consumer electronics) and a 4.7% increase in the consumption of ‘active’ appliance (such as lighting, kettles and electric showers).

Saidur et al. [9] stated that the trend of electricity consumption was rather escalating in 2006 and therefore did an estimation of the energy consumption for operating household appliances, saving of energy under policy intervention, and emission of poisonous gases in Malaysia between 1999 and 2015. The study found that refrigerator–freezer was the major energy-consuming appliance followed by air conditioner, washing machine, fan, rice cooker, and iron.

Murakami et al. [10] described the outlines in greenhouse gas emission trends in the residential and commercial building sectors in Japan. They stated that the increase in residential energy consumption in Japan was due to the widespread use of heating equipment, hot water supply apparatus, and other household electrical appliances. Moreover, the energy consumption increase in commercial energy use was mainly due to the increase of the floor area of buildings, particularly hotels, hospitals, and department stores.

Similarly, Rosas-Flores and Gálvez [11] highlighted important factors contributing to the increase include changes in the types of housing built, heating, cooling, water-heating equipment and other appliances. Trends in energy consumption between 1984–2006 by end use was reviewed over the same period. Energy use by appliances was estimated by assuming that the unit consumption was constant and penetration of appliances was the only variable. The refrigerators accounted for the highest residential electricity use in Mexican households, at 56% consumption among the main electrical appliances; air conditionings or coolers represented, on average,17%; televisions accounted for 13%, on average; irons, 5%; and washing machines, 5% of consumption for the period of the essay.

In areas such as Europe, appliance energy standards have driven appliances consumption. In 2008 Waide et al. [12] summarized the appliance energy standards available in Europe then discussing the components of the residential electricity demand by end use and the role played by appliances in it. This authors claim that although the standards were set to ensure that the models sold after 1999 would use on average 15% less energy, this did not mean that saving energy was cost-efficient then.

Later on, in 2010, Atanasiu and Bertoldi [13] assessed the final energy consumption in the European Union residential buildings over the period 2004–2007. This paper summarized the result of an in-depth survey on the electricity consumption in the EU-27 residential buildings, the main findings of the first preparatory studies for implementing the Eco-design Directive as well as other related analysis and studies. One of the aims of this paper was to show the status of electricity consumption for the main appliances and equipments, the energy efficiency progress, and estimates of the electricity-saving potential in the EU-27 residential sector at the time of the publication.

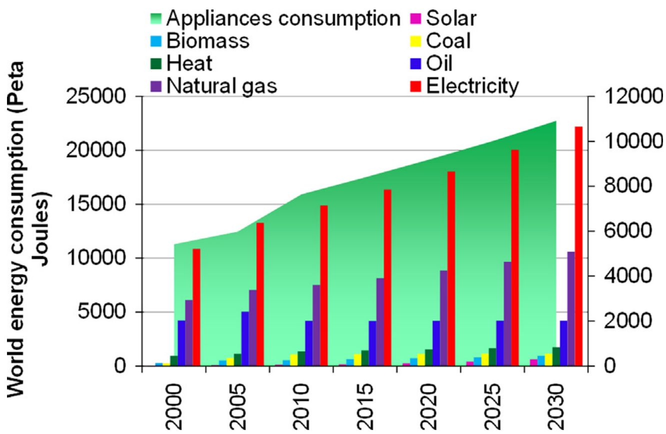


Fig. 3. World buildings energy consumption. Comparison between energy sources and appliances electricity consumption.
Source: adapted from [2].

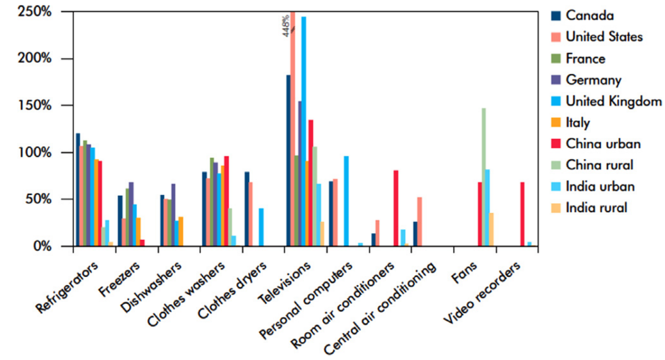


Fig. 4. Selected appliance ownership by country [2]. *Note*: Room air conditioners include "air coolers" for India. Data for India are for 1999/2000, for other countries they are for 2005 or latest available.
Source: IEA databases; LBNL (2008); National Sample Survey Organisation (2005).

Since the electricity consumption in the European Union household increased by 2% per year during the period 2001–2020, in 2011, de Almeida et al. [14] carried out and energy monitoring campaign in 12 geographically representative EU countries accompanied by a lifestyle survey. From the measurements carried out it was concluded that Information Technologies and entertainment loads were key contributors to the power demand, and that in basically all types of loads there was a wide range of performance levels in the models available in the market. The authors attributed the electricity consumption increase to an increased degree of basic comfort and level of amenities and with the widespread utilisation of new types of loads.

IEA forecasts for appliances energy consumption are presented in Fig. 3 (2000–2030). Energy consumption in buildings is expected to grow and this growth is expected to be covered by biomass mostly; electricity and demand show an increase in the demand. The growth of appliances consumption is expected to increase at a higher rate.

Energy demand in the buildings sector is driven by population, geographic region, climatic conditions, incomes, energy prices, services sub-sector value added, services sub-sector floor area and cultural factors. These elements have an impact on the number and size of households, the heating or cooling load, the number and types of appliances owned, and their patterns of use.

Traditional large appliances are still responsible for most household electricity consumption for appliances. But their share is falling rapidly as electronic home entertainment and information and communications equipment now accounts for more than 20% of residential electricity consumed in most countries. This rapid technology penetration offers opportunities to roll out more efficient appliances, but this effect to date has been overwhelmed by the increased uptake of new devices. In addition, rapid innovation in the electronics sector poses a challenge for regulators seeking to define technical specifications for efficiency, which is a time-consuming process. For example, flat-screen televisions are more efficient than the cathode ray tube technology they replaced. But sales have quickly shifted to much larger screens, cancelling efficiency benefits.[4] In developing countries, current ownership levels, even of major appliances, are often low and the potential for growth is significant. For instance, only 4% of rural households in India had refrigerators in 2002, compared to the norm of 95% to 100% in OECD households (Fig. 4).

[4] Subsequent to the introduction of flat-screen TVs, efficiency of this product has improved, particularly with the introduction of LED backlighting. This trend seems to be due to a combination of government-driven programs such as EnergyStar, and market drivers.

This paper investigates the share of trend of energy consumption of appliances in the building sector, not including space heating and cooling and lighting; therefore, this paper focusses on appliances such as refrigerators, televisions, freezers, washing machines, and consumer electronics.

2. Drivers of the energy consumption of appliances

Energy use of appliances can be decomposed in several drivers as shown in Eq. (1):

$$\text{kW h} = \sum_a h \times \frac{n}{h} \times \frac{\text{kW h}}{n} \tag{1}$$

where the following drivers are identified:

1. a appliance type (e.g. refrigerators)
2. h number of households
3. n/h number of appliances per household
4. kW henergy [kWh] used by each appliance.

There is not a complete set of data to complete this type of study, but here the authors use the survey carried out by Intertek of 251 households in England to monitor the electrical power demand and energy consumption in 2010–2011 [15].

The appliances considered in this report include more than 100 different types, from traditional appliances such as televisions and freezers, to electronic appliances such as PCs, video games or tablets.

The number of appliances per household is shown in Fig. 5. Audiovisual sites are the most commonly appearing type of appliances with televisions representing 40% of them (others included DVD, Nintendo Wii, VCR, Hi-Fi, etc.). Each household also had an average of 3 cooking appliances (kettle, microwave, cooker, toaster, etc.) and 3 computer site appliances (laptop, router, printer, desktop, monitor, etc.). The group named “Other”, which accounted for also an average of 3 per household, include sockets, vacuum cleaners, hair dryers, irons, hair straighteners, fans, etc.

The energy used by each appliance varies greatly. This report shows that in UK televisions are the appliance which represented the highest energy consumption, with over 30%, followed by audiovisual sites, cooling appliances (freezers and fridges) and clothes dryers, each of these contributing to more than 10% (Fig. 6). The report also compares the different household types in the UK and shows that all types of households in UK in 2011 contributed to the same percentage on the average energy consumption of the country, about 10% (Fig. 7).

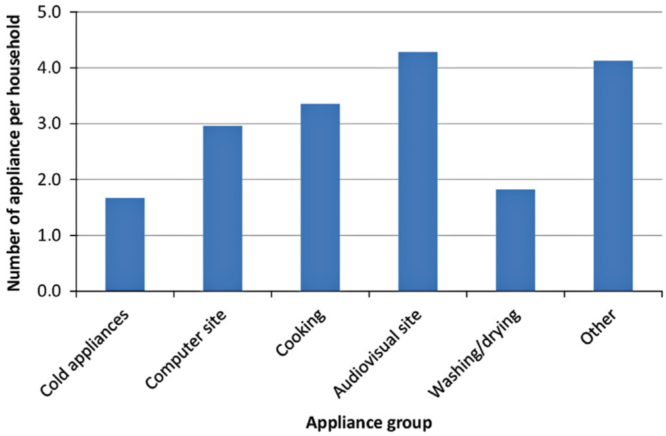


Fig. 5. Number of appliance per household in UK.
Source: adapted from [15].

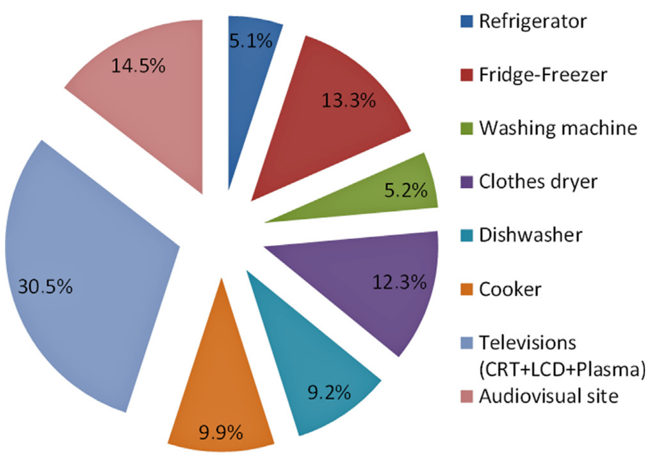


Fig. 6. Contribution of each appliance type to the average energy consumption of appliances in UK.
Source: adapted from [15].

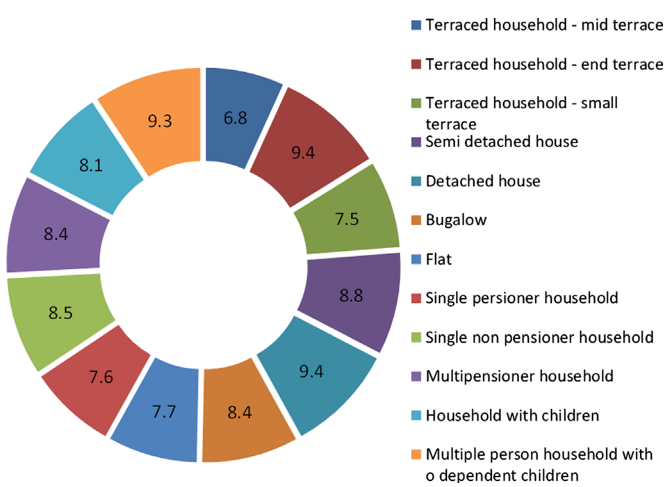


Fig. 7. Contribution of each household type to the energy consumption of appliances in UK.
Source: adapted from [15].

Fig. 8 shows the average energy consumption of each appliance in the different household types evaluated. The study shows that the households without children have an average energy consumption in most appliances (except freezers), while pensioners consume less energy (except cooling appliances). The biggest

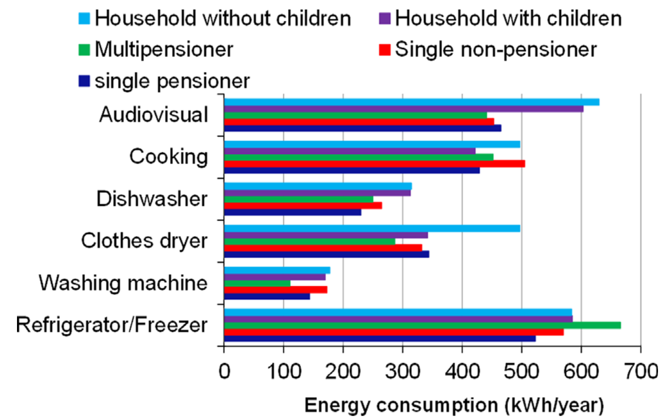


Fig. 8. Energy consumption (kWh/year) of different appliances per household type.
Source: adapted from [15].

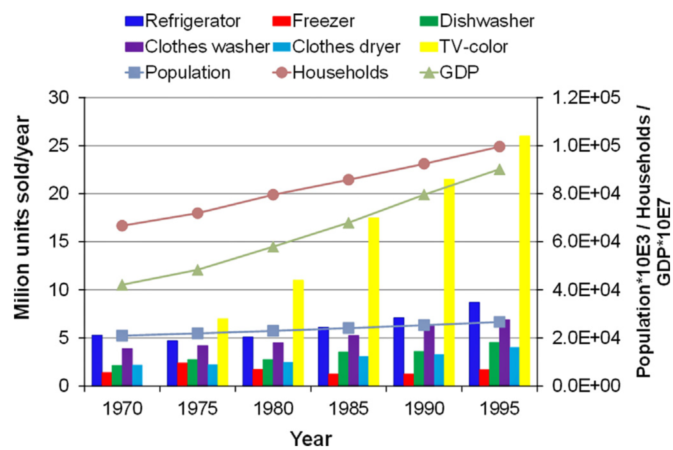


Fig. 9. US appliance yearly sales: Number of selected appliances sold yearly in total.
Source: number of appliances adapted from [16], population from [17], households from [18] and GDP from [19].

differences are seen in audiovisual appliances, households with pensioners have a lower energy consumption and in clothes dryers, here as expected households without children show higher average energy consumption.

3. Trends in appliances deployment

In this section, the trends in appliances energy consumption for different regions in the world are compared. US, China and India are presented, US representing the developed areas of the world, China as a developing country were saturation in appliances deployment is reached, and India as a developing country were saturation is still not reached.

For the US, historical data was published by the Lawrence Berkeley National Laboratory in 1997. This study gives the number of six different appliances (refrigerator, freezer, dishwasher, clothes washer and clothes dryer) sold from 1970 to 1995. Fig. 9 shows that television deployment follows the same trend as the US population and US households growth, while all others appliances do not show a deployment increase, but a constant deployment trend.

Figs. 10 and 11 show the number of certain appliances (television, refrigerator, computer, clothes washer and fan) for the period 1980–2010 in China urban and rural, respectively.

The data for China show several interesting effects. First, the most highly desired major appliances – refrigerators and clothes washers – are by now present in nearly every urban Chinese

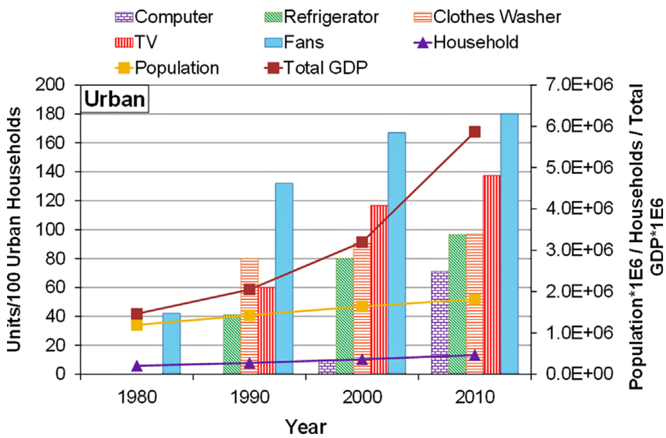


Fig. 10. Number of appliances in urban households in China (1980–2010). *Source*: adapted from [20], population from [17], households from [18] and GDP from [19].

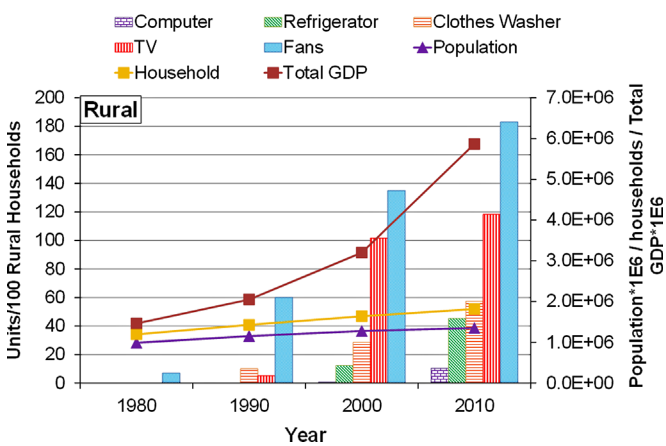


Fig. 11. Number of appliances in rural households in China (1980–2010). *Source*: adapted from [20], population from [17], households from [8] and GDP from [19].

home. As a result, the ownership rate per household of these goods is slowing as it approaches one per household. The average urban household already has multiple fans and televisions, and near universal computer ownership seems to be on the horizon. The picture is different of course for rural households, where only half of households have refrigerators or clothes washers. In this sector, too, however, appliance ownership is experiencing a rapid rise. This effect, together with rapid urbanization in China will drive total appliance energy consumption higher in that country, albeit with some saturation effects already present. Another factor at play in the energy consumption of appliances in China is their size. Chinese households are generally much smaller in terms of floor area than those in the U.S. and Europe. They have historically used much smaller refrigerators, and small “impeller type” clothes washers. Recent data show a strong trend toward larger refrigerators, while still compact compared to those used in the United States, and European-style drum clothes washers that consumer much more energy than the older-style washers. Televisions, too, are getting larger in China, although they have not yet caught up to the very large sizes used in U.S. and European homes.

The forecast of appliance ownership (measured as number of shipments, where shipments are calculated as the sum of the first purchases and replacements) in India growth is remarkably high when using BUENAS model [21]. This is essentially an effect of diffusion threshold. With economic growth rates of about 5% (i.e. high, but slower than the current growth rate), average income

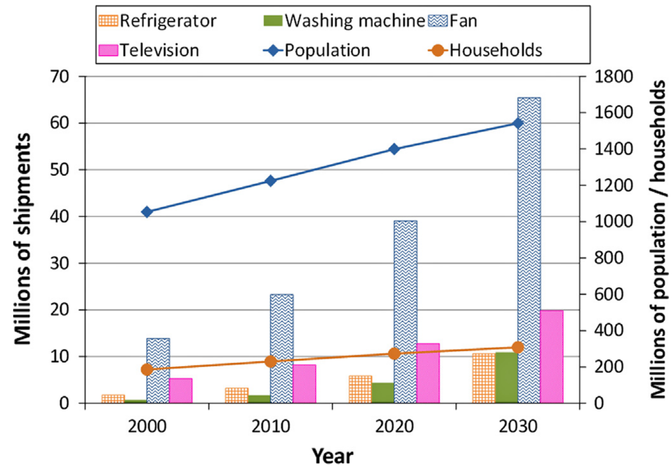


Fig. 12. Forecast of the number of shipments of appliances in India (2000–2030). *Source*: adapted from [21], population from [17] and households from [18].

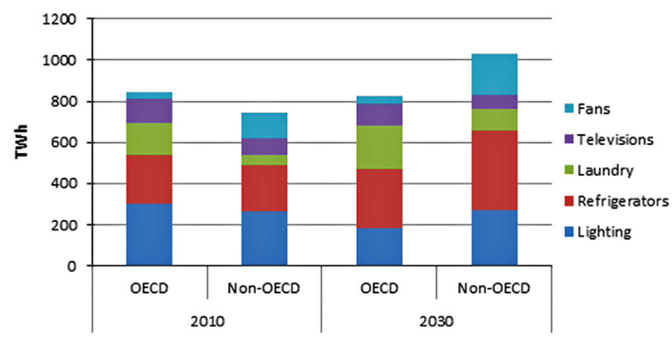


Fig. 13. BUENAS modeled residential electricity consumption by end use. *Source*: adapted from [22].

will increase by about a factor of four by 2030. The model predicts that a large fraction of households will own most major appliances. This will lead to an enormous growth in consumption, because diffusion rates are currently so low. This will not be surprising if we believe that the average Indian household will in 25 years time have the consumption power that the middle-class currently do. If, on the other hand, the great majority of households remain poor, the model would likely overestimate future consumption.

In this way, the situation in India is distinct from China. In India, saturation effects are much less apparent than in China (Fig. 12). Even with significant economic growth, it is likely that a significant fraction of the urban poor in India will be major appliance users. On the other hand, a large and relatively affluent urban middle class could use many times the energy on appliances as the country as a whole does today. This is a matter of serious concern to energy planners in India, where electricity shortages are already a daily occurrence and at times are catastrophic.

A forecast of electricity demand for selected appliances in thirteen major economies that account for most of the world's energy consumption is carried out using BUENAS model [22] (Fig. 13).[5]

Several notable trends can be observed in Fig. 13. First of all, the energy consumption of major appliances in the six major non-OECD countries is already nearly equal to consumption in the OECD, due to their large populations and widespread adoption of

[5] BUENAS includes OECD countries Australia, Canada, the EU, Japan, Rep. of Korea, Mexico and the United States as well as non-OECD countries Brazil, China India, Indonesia, Russia and South Africa.

the main white goods and lighting. Also, while fans are a minor end use in most OECD countries, they are extremely popular in the warm developing countries, where mechanical air conditioning is largely unaffordable. By 2030, energy consumption in the non-OECD countries has grown by nearly 40%, while it has decreased slightly in the OECD. This based on the assumption that much of the most significant efficiency gains will be in lighting (elimination of incandescent lamps). While this efficiency gain will also occur in non-OECD countries, it will be compensated by increased lighting use over all. Likewise, increased uptake of all other appliances combined with population growth will continue to drive consumption in the non-OECD countries. It is important to note that the vast majority of appliances operating in 2030 have yet been manufactured, so there is a significant opportunity to implement efficiency now, to further reduce consumption in OECD countries, and mitigate much of the growth in the non-OECD countries.

4. Conclusions

Literature presents some trends in national energy consumption in appliances in different countries in the world and in different time spans. Any comparison is not possible since the assumptions and variables are very different in each study.

Trends show that appliances account for an increasing amount of building energy consumption, and are disproportionately powered by electricity. These trends are partially due to the proliferation of electronics and other small household devices, which have dramatically increased the sheer number of energy consuming devices in the average home, especially in OECD countries. An equally important underlying driver of appliance energy efficiency, however, is household income growth in non-OECD countries. This trend, which have already brought millions of households out of poverty in China and India and promises to continually improve standards of living throughout the developing world, will also have a major impact on appliance energy consumption as many more households will be able to afford basic equipment such as refrigerators and washing machines.

On one hand, these trends are concerning. Because appliances generally consume electricity instead of renewable fuels or direct combustion fuels, they carry a relatively large carbon footprint in countries where electricity production is carbon intensive. In addition to greenhouse gas emissions, rapid uptake of appliance ownership in the household sector can strain already stretched electricity grids, leading to supply shortages that in turn risk health and cause economic damage. On the other hand, appliances present significant opportunities for efficiency improvement. In fact, appliance efficiency improvement has been shown to be highly cost effective compared to efficiency improvement in other sectors, or renewables [23]. Finally, because they are electric, appliances may ultimately run on renewable energy produced at the home or by the grid.

In conclusion, this paper was intended to give an overall picture of how appliances fit into the global energy demand picture, and how their contribution is likely to evolve. The authors hope that it serves as a reference to energy researchers and climate policy makers alike, and will lead to further discussion and investigation of the dynamics of this important energy demand sector.

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